

## DESCRIPTION

DISCHARGE LAMP BALLAST WITH DETECTION OF ABNORMAL DISCHARGE OUTSIDE THE ARC TUBE

### TECHNICAL FIELD

The present invention is directed to a discharge lamp ballast, and more particularly to an electronic lamp ballast that detects an abnormal arc discharge occurring outside of an arc tube for limiting or interrupting an AC output power being fed to the discharge lamp upon detection of the abnormal arc discharge.

### BACKGROUND ART

An electronic discharge lamp ballast has been accepted as having an inherent capability of providing a relatively high re-ignition voltage to a discharge lamp reaching its near end of lamp life for prolonging the lamp life. However, this advantage may sometimes cause the lamp to suffer from undue stress which would deteriorate an arc tube of the discharge lamp. The typical deterioration is a leakage of a filling gas out of the arc tube. Once the leakage becomes critical, an abnormal arc discharge would occur within an envelop surrounding the arc tube when supplying the AC output power to the arc tube. That is, the abnormal arc discharge would develop between an electrode of the arc tube and a certain conductive part within the envelope. If such abnormal arc discharge continues, the discharge lamp would be damaged.

Also, if there be any discontinuity in the electric feeding line from the ballast to the discharge lamp due to the disconnection or a dielectric breakage in a covering of the feeding line, like abnormal arc discharge would develop in the feeding line, thereby damaging the ballast, the connection, and/or the discharge lamp itself.

### DISCLOSURE OF THE INVENTION

In view of the above problem, the present invention has been accomplished to provide a novel discharge lamp ballast which is capable of discriminating the abnormal arc discharge occurring outside of the arc tube and limiting an AC output power being fed to the discharge lamp for safe operation of the discharge lamp. The ballast according to the present invention is provided for operating the discharge lamp of the type having the arc tube and an envelope surrounding the arc tube. The ballast includes an igniter that provides a high frequency ignition voltage in order to develop an arc in the arc tube for starting the discharge lamp, and an AC power unit that provides a low frequency AC output power to the arc tube for operating the discharge lamp after the lamp is ignited. A detector is included to examine an electric characteristic of an arc discharge occurring outside of the arc tube after the discharge lamp is ignited. The detector analyzes the electrical characteristic to determine an abnormal discharge when there is a critical change in the electrical characteristic. Also included in the ballast is a limiter that limits the AC output power from the AC power unit upon determination of the abnormal discharge, thereby enabling the safe operation of the discharge lamp.

Preferably, the detector is configured to examine the electric characteristic of the arc discharge occurring within the envelope.

The detector may be configured to give a first logic for determination of the abnormal discharge. For this purpose, the detector includes a lamp monitor for monitoring a lamp parameter which is one of a lamp voltage and a lamp current being applied to the discharge lamp, and an analyzer for determination of the abnormal discharge. The lamp monitor monitors the lamp parameter once within each of positive and negative half-cycles of the AC output

power, while the analyzer compares the lamp parameter in each of the positive and negative half-cycles with a predetermined threshold, and increments an error count when the lamp parameter exceeds the threshold. The analyzer determines the abnormal discharge when the error count exceeds a predetermined count.

The detector may be also configured to give a second logic for determination of the abnormal discharge. In this case, the lamp monitor is set to monitor the lamp parameter once within at least one of the positive and negative half-cycles of the AC output power, and the analyzer is set to compare the lamp parameter with a predetermined threshold and to give a flag when the lamp parameter exceeds the threshold. The analyzer compares the next lamp parameter with the threshold and increments an error count when the next lamp parameter does not exceed the threshold and also when the flag has been set with regard to the previous lamp parameter. Then, the analyzer determines the abnormal discharge when the error count exceeds a predetermined count.

Alternatively, the lamp monitor may be configured to monitor the lamp parameter once within each of positive and negative half-cycles. In this case, the analyzer designates the lamp parameter monitored in each of the positive and negative half-cycles as a first lamp parameter, and designating the lamp parameter monitored in the successive one of the positive and negative half-cycles as a second lamp parameter. The analyzer acts to compare the first lamp parameter with a predetermined first threshold to give a first flag when the first lamp parameter exceeds the first threshold, and to compare the second lamp parameter with a predetermined second threshold to give a second flag when the second lamp parameter exceeds the second threshold. Then, the analyzer

compares the next first lamp parameter with the first threshold and increments a first error count when the next first lamp parameter does not exceed the threshold and also when the first flag has been set with regard to the previous first lamp parameter. Likewise, the analyzer compares the next second lamp parameter with the second threshold and increments a second error count when the next second lamp parameter does not exceed the second threshold and also when the second flag has been set with regard to the previous second lamp parameter. The analyzer determines the abnormal discharge either when the first error count exceeds a predetermined count or when the second error count exceeds a predetermined count.

Further, the detector may be configured to give a third logic for determination of the abnormal discharge. In this case, the analyzer is set to compare the lamp parameter in each of the positive and negative half-cycles with a first threshold and also with a second threshold which is lower than the first threshold. The analyzer increments a first error count when the lamp parameter is greater than the first threshold, and increments a second error count when the lamp parameter is lower than the second threshold. Then, the analyzer determines the abnormal discharge either when the first error count exceeds a first value or when the second error count exceeds a second value.

Still further, the detector may be configured to give a fourth logic for determination of the abnormal discharge. In this instance, the lamp monitor monitors the lamp parameter once within each of positive and negative half-cycles, and the analyzer is set to designate the lamp parameter monitored in each of the positive and negative half-cycles as a first lamp parameter, and designating the lamp parameter monitored in the successive one of the positive

and negative half-cycles as a second lamp parameter. The analyzer obtains the a difference between the first and second lamp parameters, and increments an error count when the difference exceeds a predetermined threshold, thereby determining the abnormal discharge when the error count exceeds a predetermined count.

Further, the detector may be configured to give a fifth logic for determination of the abnormal discharge. In this instance, the detector includes the like lamp monitor and the analyzer which is set to designate the lamp parameter monitored in each of the positive and negative half-cycles as a first lamp parameter, and designate the lamp parameter monitored in the successive one of the positive and negative half-cycles as a second lamp parameter. The analyzer compares the first lamp parameter with the second lamp parameter, and incrementing an error count when the first lamp parameter is greater than the second lamp parameter multiplied by a predetermined value. Then, the analyzer determines the abnormal discharge when the error count exceeds a predetermined count.

Moreover, the detector is preferred to make all of the first, second, third, fourth and fifth logics as mentioned in the above, and to determine the abnormal discharge when anyone of these logics is satisfied.

Preferably, the detector, which is utilized to make anyone of the above logics, may include an initializer that disables the analyzer until the positive and negative half-cycles repeat a predetermined number of times.

These and still other advantageous features of the present invention will become apparent from the detailed description of the preferred embodiment when taken in conjunction with the attached drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram illustrating a discharge lamp ballast in accordance with a preferred embodiment of the present invention;

FIG. 2 is a waveform chart illustrating a basic operation of the above ballast;

FIG. 3 is a flow chart illustrating various schemes of determining an abnormal discharge according the present invention;

FIGS. 4 to 7 are flow charts respectively illustrating the details of above schemes; and

FIGS. 8 to 11 are graphs respectively illustrating lamp characteristics when the discharge lamp suffers from the abnormal discharge.

## MODE FOR CARRYING OUT THE INVENTION

Now referring to FIG. 1, there is shown a circuit diagram of a discharge lamp ballast according to the preferred embodiment of the present invention. The ballast is designed to operate a discharge lamp, particularly a high-intensity discharge lamp **L** composed of an arc tube **1** and an envelope **6** surrounding the arc tube. The arc tube **1** is filled with a metal halide in addition to the mercury and an inert gas, while the envelope **6** is evacuated. The ballast includes a rectifier **10** that provides a DC voltage from an AC voltage source, a DC-DC converter **20** that converts the rectified DC voltage into a smoothed DC voltage, and an inverter **30** that provides a low frequency AC output power or voltage to the discharge lamp **L**. The DC-DC converter **20** is of a type known as a step-up chopper including a switching transistor **21** connected in series with an inductor **22** across the rectifier **10**, and a smoothing capacitor **24** connected in series with a diode **26** across the switching transistor **21**. The switching transistor **21** is

controlled to turn on and off at a suitable frequency to accumulate the smoothed DC voltage across the capacitor **24**.

The inverter **30** includes four switching elements, i.e., FETs **31** to **34** which are arranged in a full-bridge configuration that has an input connected across the smoothing capacitor **24** and has an output connected for applying the AC output voltage to the discharge lamp **L**, i.e., across electrodes of the arc tube **1**. Also included in the inverter **30** is an inductor **35** connected in series with the discharge lamp **L** between the connection point of the first FET **31** with the second FET **32** and the connection point of the third FET **33** with the fourth FET **34**. A capacitor **36** is connected across the discharge lamp **L** between the connection points. The FETs are driven by drivers **37** and **38** under the control of a controller **60** to turn on and off in a manner as shown in FIG. 2 for providing the low frequency AC output power to the discharge lamp **L**. As shown in FIG. 2, the AC output power is applied after a high frequency ignition voltage is applied to the discharge lamp. In this sense, the FETs **31** to **34**, the inductor **35** and the capacitor **36** constitute an AC power unit that provides the low frequency AC output power to the discharge lamp **L**.

The high frequency ignition voltage is generated by an igniter which is integrated in the inverter **30** and includes, in addition to the FETs **31** to **34**, a series resonant circuit of an inductor **41** and a capacitor **42** connected across the second FET **32**. The FETs **31** to **34** are controlled by the controller **60** to turn on and off at a high frequency, as shown in FIG. 2, thereby generating the high frequency ignition voltage to the discharge lamp **L**. The controller **60** is set to give an ignition period in which the ignition voltage is generated, and subsequently give a lamp operation period in which the low frequency AC output

power is generated.

In the ignition period, FETs **31** and **32** are controlled to turn on and off alternately with FETs **34** and **33** being turned on and off alternately in synchronism with FETs **31** and **32**, respectively, all at the high frequency, for example, several tens of KHz to several hundreds of KHz to resonate the circuit of inductor **41** and the capacitor **42**, thereby inducing the high ignition voltage to ignite the lamp **L**. The ignition period is set to last about several tens of milliseconds. Although not shown in FIG. 2, the ignition period is followed by a judgment period of about several milliseconds during which one of FETs **31** and FET **32** is kept turned on, and also one of FETs **33** and **34** are driven to turn on and off at a high frequency to provide a lamp voltage, in the like fashion as seen in a first half cycle of the lamp current  $I_L$  of FIG. 2. It is within this judgment period that the controller **60** investigates the lamp voltage to determine whether or not the lamp is successfully ignited. If the lamp is judged not to be ignited, the controller **60** repeats setting the ignition period at an interval of several hundreds of milliseconds in which all of FETs are set to turned off, until the lamp is ignited or the elapse of a predetermined starting period. The lamp voltage is obtained by a voltage divider network of resistors **51** to **54** connected across the discharge lamp **L**.

In the lamp operation period, one of the diagonal pair of FETs **31**, **34** and the diagonal pair of FETs **32**, **33** is made active, while the other is made inactive, thereby providing the low frequency AC power. The controller **60** includes a power table **64** that stores a voltage-wattage relation for the discharge lamp specified, and a power controller **62** that refers to the power table **64** and retrieves a required lamp power in match with the detected lamp voltage for



controlling FETs 31 and 34 in order to supply the proper AC lamp power to the discharge lamp L. In this embodiment, the lamp voltage is given by an absolute difference between the voltage across resistor 52 and the voltage across resistor 54. In this sense, the voltage divider network defines a lamp monitor for monitoring the lamp voltage.

The lamp monitor is cooperative with an analyzer 72 to define a detector 70 which examines an electric characteristic of an arc discharge occurring outside of the arc tube 1 after the lamp is ignited, and analyzes the electrical characteristic and determines an abnormal discharge when there is a critical change in the electrical characteristics of the lamp voltage or current. When the abnormal discharge is determined, a limiter 80 in the controller 60 is activated to limit or interrupt the AC power being supplied to the discharge lamp for safe operation of the lamp.

Prior to discussing the detailed functions of the analyzer 72, it is noted that the abnormal discharge occurs when the arc tube is damaged. The abnormal discharge in this case may be referred to as an inside-envelope discharge since the arc discharge will occur within the envelope and not within the arc tube. FIGS. 8 to 10 show some of the electrical characteristics typically seen at the event of the inside-envelope discharge. The characteristics of FIGS. 8 and 9 are identified to have an abrupt increase of the lamp voltage (re-ignition voltage) immediately after the voltage reversal of the lamp voltage, and to have an abrupt overshooting of the lamp current immediately after the extinction of the abrupt voltage increase. In the condition of FIG. 8, the arc discharge becomes unstable, resulting in the repetition of the lamp extinction and re-ignition. In the condition of FIG. 9, a half-wave discharge occurs within the envelope, assisting

to sustain the arc discharge. In addition, the lamp voltage is seen to fluctuate to a large extent in both cases.

The characteristic of FIG. 10 is identified to have an unduly high lamp voltage far beyond the rated lamp voltage. This condition results from the arc discharge occurring immediately adjacent to the electrode of the arc tube within the envelope, and such arc discharge is rather stable not to cause the lamp extinction, which should be avoided.

The analyzer 72 realizes five independent logics each analyzing the electric characteristic of the lamp parameter, i.e., the lamp voltage for determination of the abnormal discharge, and causes the limiter 80 to limit or interrupt the AC output power when any one of the five logics determines the abnormal discharge.

The analyzer 72 is configured to execute the logics during a control sequence of igniting and operating the lamp. As shown in FIG. 3, the control sequence is composed of steps (1) to (11). Firstly, the igniter is activated at step (1) to apply the ignition voltage for starting the lamp, followed by step (2) in which the lamp voltage is read by the analyzer 72. As step (3), the lamp voltage ( $V_{la}$ ) is compared with a predetermined maximum voltage ( $V_{max}$ ). When  $V_{la} > V_{max}$ , no ignition is recognized and the sequence returns to step (1). Otherwise, the ignition is found to be successful, and step (4) is executed to provide the lamp voltage in the positive half-cycle, as shown in FIG. 2, for feeding the lamp current or power to discharge lamp under the control of the power controller 62. Then, step (5) is executed to read the lamp voltage once monitored in the positive half-cycle in order to compare the lamp voltage ( $V_{la}$ ) with a predetermined threshold ( $V_{TH}$ ) at step (6). When  $V_{la} > V_{TH}$ , the analyzer 72 recognizes the abnormal discharge and initiates the first logic, as will be discussed later.

Otherwise, no abnormal discharge is found to take place and the sequence goes to step (7) to reverse the polarity, i.e., the controller **60** responds to feed the lamp current in the negative half cycle, as shown in FIG. 2. Thereafter, steps (8) to (11), which are similar to steps (4) to (7), are executed for monitoring and comparing the lamp voltage in the negative half-cycle with the threshold ( $V_{TH}$ ).

#### Operation of the first logic

The first logic is explained with reference to FIG. 3. The first logic watches the steps (6) and (10) and includes the steps (101) to (105). When the lamp voltage once monitored in the positive half-cycle of the AC output power exceeds the threshold ( $V_{la} = V_{TH}$ ) at step (6), the analyzer **72** makes the step (101) of incrementing an error count by one. Likewise, when ( $V_{la} = V_{TH}$ ) at step (10), the step (102) is made to increment an error count by one. While the AC output power repeats a number of the positive and negative half-cycles, steps (103) and (104) are made to check whether or not the error count exceeds a predetermined count (max). If anyone of the steps (103) and (104) finds the error count exceeding the predetermined count, the sequence goes to a step (105) where the analyzer **72** responds to issue a first alarm to the limiter **80**, causing the controller **60** to limit or interrupt the AC output power being fed to the discharge lamp. Otherwise, the sequence goes back to the step (1) for re-ignition of the lamp.

#### Operation of the second logic

Referring to FIG. 3, the second logic is inserted between the steps (6) and (7) and also between the steps (10) and (11) for checking the lamp voltage once monitored in each of the positive and negative half-cycles. As shown in FIG. 4, the second logic includes the steps (201) to (207). At step (201), the lamp

voltage (Vla1) in each positive half-cycle, and the lamp voltage (Vla2) in each negative half-cycle are compared respectively with predetermined first threshold (VTH1) and second threshold (VTH2) which may be equal. When  $Vla1 > VTH1$ , a flag is set to "1" at step (202) and the sequence goes back to step (7) or (11) of FIG. 3. Likewise, when  $Vla2 > VTH2$ , the flag is set to "1" at step (202) and the sequence goes back to step (7) or (11).

In the next positive and negative half-cycles, it is firstly checked at step (201) whether  $Vla1 > VTH1$  or  $Vla2 > VTH2$ . If one of these equations is not satisfied, then it is checked at step (203) whether or not the flag has been set to "1" in the previous corresponding one of the positive and negative half-cycles. If the flag has not been set to "1", the sequence goes back to step (7) or (11) of FIG. 3. Otherwise, an error count is incremented by one at step (204), followed by step (205) where the flag is reset to "0". Subsequently, it is checked at step (206) whether or not the error count exceeds a predetermined count (max). If the error count exceeds the predetermined count, the sequence proceeds to a step (207) where the analyzer 72 responds to issue a second alarm to the limiter 80, thereby causing the controller 60 to limit or interrupt to the AC output power being fed to the discharge lamp. Otherwise, the sequence goes back to step (7) or (11).

#### Operation of the third logic

The third logic is also inserted between the steps (6) and (7) and also between the steps (10) and (11) for checking the lamp voltage once monitored in each of the positive and negative half-cycles. As shown in FIG. 5, the third logic firstly checks at step (301) and (302) respectively whether or not the lamp voltage (Vla) is higher than a predetermined high threshold (VH) and whether or not the lamp

voltage ( $V_{la}$ ) is lower than a predetermined low threshold ( $V_L$ ). If  $V_L < V_{la} < V_H$  indicating that the lamp voltage is within the normal range, the sequence goes back to step (7) or (13). If  $V_{la} = V_H$ , an error count is incremented by one at step (303) and thus incremented error count is compared with a predetermined count (max) at step (305). If the error count = max, the sequence proceeds to a step (307) where the analyzer 72 responds to issue a third alarm to the limiter 80, thereby causing the controller 60 to limit or interrupt to the AC output power being fed to the discharge lamp. Otherwise, the sequence goes back to step (7) or (13). Likewise, if  $V_{la} = V_L$ , an error count is incremented by one at step (304) and thus incremented error count is compared with a predetermined count (max) at step (306). If the error count = max, the sequence proceeds to a step (308) where the analyzer 72 responds to issue the third alarm to the limiter 80, thereby causing the controller 60 to limit or interrupt to the AC output power being fed to the discharge lamp. Otherwise, the sequence goes back to step (7) or (11).

#### Operation of the fourth logic

The fourth logic is inserted in a bypath extending across the steps (7) and (10) of FIG. 3 in order to examine the lamp voltage once monitored within each one complete cycle of the AC output power being fed to the discharge lamp. Referring to FIG. 6, the fourth logic starts with a step (401) where the lamp voltage ( $V_{la1}$ ) once monitored in the positive half-cycle is compared with the lamp voltage ( $V_{la2}$ ) once monitored in the negative half-cycle to examine whether the difference ( $V_{la1} - V_{la2}$ ) between the voltages is greater than a predetermined threshold (TH). If  $V_{la1} - V_{la2} < TH$ , the sequence goes back to step (11) of FIG. 3. Otherwise, i.e., the difference is found critical, an error count is incremented by one at step (402). At step (403), it is checked whether

the error count increases to exceed a predetermined count (max) while the AC output power continues to be supplied. When the error count exceeds the predetermined count, the sequence proceeds to a step (404) where the analyzer 72 responds to issue a fourth alarm to the limiter 80, thereby causing the controller 60 to limit or interrupt to the AC output power being fed to the discharge lamp. Otherwise, the sequence goes back to step (11).

#### Operation of the fifth logic

The fifth logic is also inserted in the bypath across the steps (7) and (10) of FIG. 3 in order to examine the lamp voltage once monitored within each one complete cycle of the AC output power being fed to the discharge lamp. Referring to FIG. 7, the fifth logic starts with a step (501) where the lamp voltage (Vla1) once monitored in the positive half-cycle is compared with the lamp voltage (Vla2) once monitored in the negative half-cycle to examine whether  $Vla1 > Vla2 \cdot k$  is satisfied, wherein k is a constant. If  $Vla1 = Vla2 \cdot k$ , the sequence goes back to step (11) of FIG. 3. Otherwise, the difference between the voltages is found critical, and an error count is incremented by one at step (502). At step (503), it is checked whether the error count increases to exceed a predetermined count (max) while the AC output power continues to be supplied. When the error count exceeds the predetermined count, the sequence proceeds to a step (504) where the analyzer 72 responds to issue a fifth alarm to the limiter 80, thereby causing the controller 60 to limit or interrupt to the AC output power being fed to the discharge lamp. Otherwise, the sequence goes back to step (11).

Thus, when any of the above logics give the alarm, the controller 60 responds to limit or interrupt the AC output power for safe operation of the

discharge lamp.

In addition, the controller **60** is programmed to give an initialize module that disables the analyzer **72** until the positive and negative half-cycles repeat a predetermined number of times.

Beside the inside-envelope discharge as explained in the above, there is another abnormal discharge which would occur when there is a defect in an electric feeding line from the ballast to the lamp. In this case, the arc discharge will occur between conductors in the electrical feeding line. When the discharge is seen outside of the envelope, it shows electrical characteristic as shown in FIG. 11, in which voltage fluctuates greatly across the conductors. Therefore, it is also made to limit the AC lamp power upon occurrence of the abnormal discharge of this type by detecting the voltage change in the electric feeding line. For this purpose, the detector **70** may be additionally equipped with a line voltage monitor for monitoring the voltage difference between the conductors.

Although the above embodiment is explained to rely on the lamp voltage or the other voltage as the lamp parameter for detection of the abnormal discharge, it is equally possible to rely on the lamp current or the equivalent thereof. Therefore, the present invention should not be limited to the use of the lamp voltage alone, and should be interpreted to encompass the use of the lamp current or the equivalent thereof.

Further, it should be noted that one or any combination of the above logics may be suffice to identify the abnormal discharge and to limit or interrupt the AC output power.